



National Aeronautics and
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Passive vs. Parachute System Trade Applied to the Multi-Mission Earth Entry Vehicle Concept

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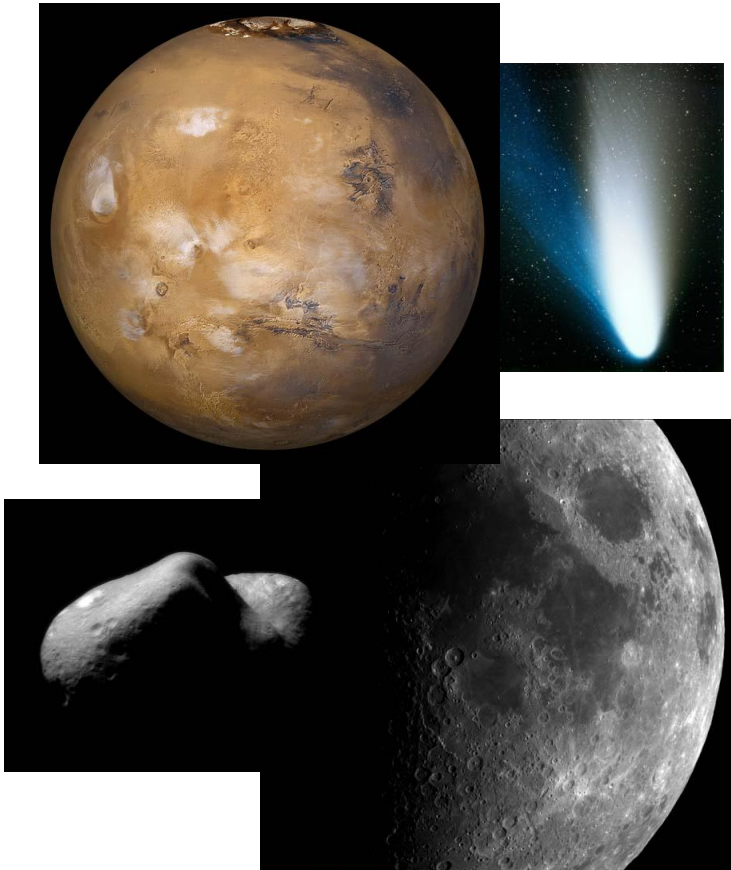
Why MMEEV?



- **The Multi-Mission Earth Entry Vehicle concept was first introduced at the 6th International Planetary Probe workshop in 2008^[1].**
 - Began as an internal LaRC development in 2006 as a follow-up to the work done in support of the Mars Technology Program.
 - Between 2008-2013, development was directed by NASA's In-Space Propulsion Technology Development Program.
 - Since FY13, NASA has provided internal/center resources to the development of MMEEV hardware designs.
- **The highly reliable MSR EEV concept provides a logical foundation upon which any sample return mission can build in optimizing an EEV design that meets their specific needs.**
 - By preserving key design elements, the MMEEV concept provides a platform by which key technologies can be identified, designed, developed and flight proven prior to implementation on MSR.
 - By utilizing a common, yet flexible design concept, any sample return mission, particularly MSR, could benefit from technology development and even flight experience, resulting in significant risk and development cost reductions.

[1] Maddock R. W. et al. (2008) Multi-Mission Earth Entry Vehicle Design Trade Space and Concept Development Strategy, IPPW6 (presentation).

MMEEV Concept Trade Space



➤ **MMEEV design requirements can vary greatly across sample return missions.**

- Payload accommodations
- Entry conditions
- Vehicle constraints (e.g. size)
- Landing requirement (velocity vs. load)

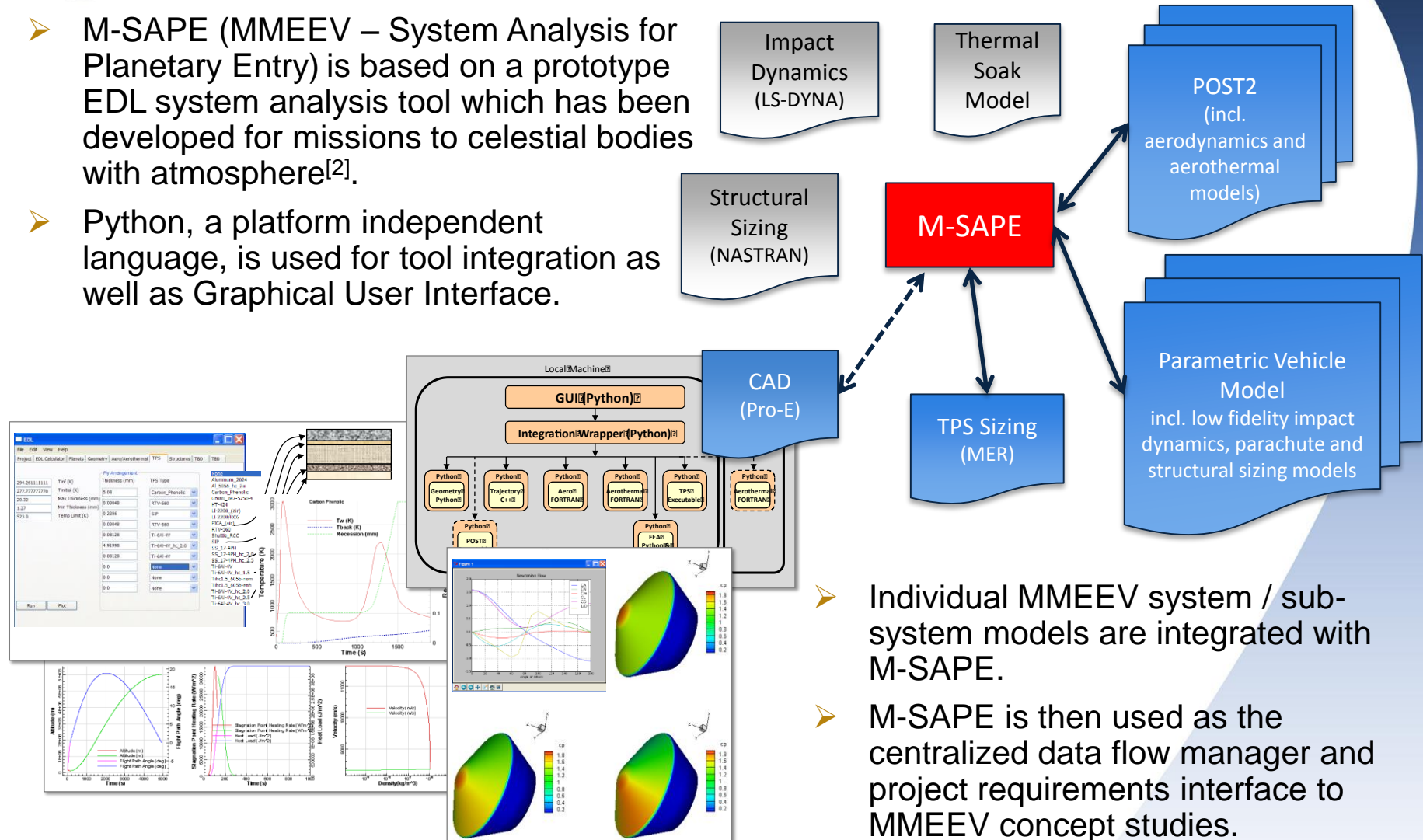
➤ **MMEEV performance is characterized across the trade space in several areas of likely interest to sample return missions.**

- Vehicle (entry) mass and configuration
- Aerodynamics and Aeroheating
- Structural loading
- Impact dynamics
- Thermal soak

The goal is to provide a qualitative performance comparison across a trade space which expands all likely robotic sample return missions. From this, each mission can use that region of the trade space which meets its particular requirements and use the resulting MMEEV design point as the basis of an optimized design.



- M-SAPE (MMEEV – System Analysis for Planetary Entry) is based on a prototype EDL system analysis tool which has been developed for missions to celestial bodies with atmosphere^[2].
- Python, a platform independent language, is used for tool integration as well as Graphical User Interface.



- Individual MMEEV system / sub-system models are integrated with M-SAPE.
- M-SAPE is then used as the centralized data flow manager and project requirements interface to MMEEV concept studies.

[2] Samareh J. A. et al. (2014), *Multi-Mission System Analysis for Planetary Entry (M-SAPE) Version 1*, NASA/TM-2014-218507.

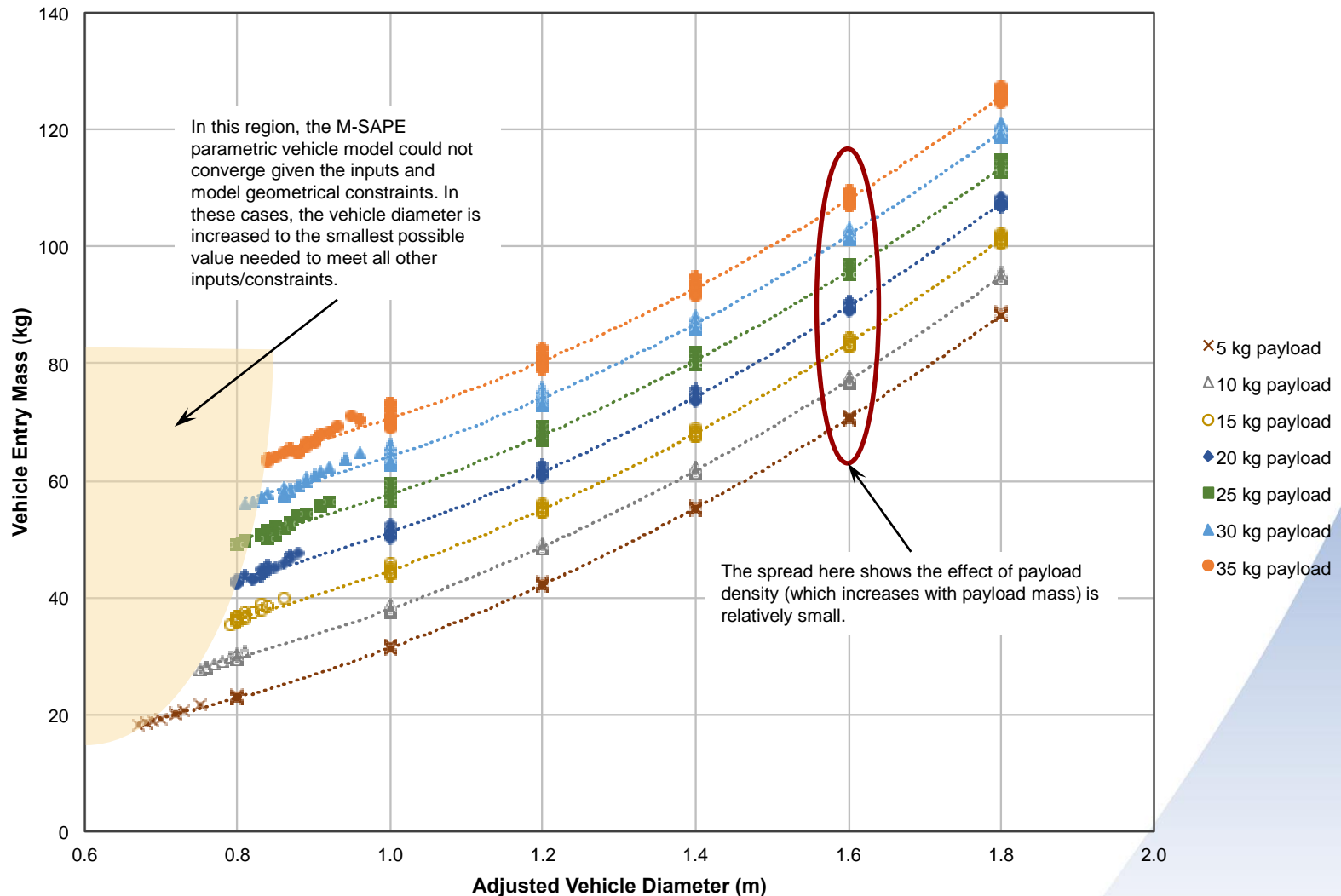


Passive vs. Active Vehicle Trade Study



- **The objective of this trade study is to determine under what circumstances might a fully passive EEV, or one which utilizes a parachute system (active vehicle), be more beneficial.**
 - One possible metric of interest is the payload mass efficiency (the ratio of payload mass to vehicle entry mass) which provides a means of quantifying how much of the entry mass can be allocated to the payload system (and thus, the sample itself).
 - Other factors, such as landing footprint, overall system complexity (e.g. packaging), system reliability, risk, and development cost also need to be considered.
- **The M-SAPE tool was first used to generate a dataset which covers the vehicle and mission trade space to consider:**
 - Impact Load Limit (I_i): 500 to 2500 g
 - Payload Mass (m_{pay}): 5 to 35 kg
 - Payload Density: 2000 to 6000 kg/m³
 - Vehicle Diameter (D_v): 0.6 to 1.8 m

M-SAPE Passive Vehicle Model (for a 1500 g landing load)





M-SAPE Passive Vehicle Model Analytical Correlations



- **An analysis of the M-SAPE dataset was then completed to develop a Mass Estimating Relationship (MER) between the vehicle entry mass and the trade space input parameters.**

$m_{\text{entry}} = A \cdot D_v^2 + B \cdot D_v + C$, where:

A, B, and C are in the form of $A = D \cdot m_{\text{pay}}^2 + E \cdot m_{\text{pay}} + F$, and

D, E, and F are functions of the impact load limit (e.g. $D = a \cdot l_i^4 + b \cdot l_i^3 + c \cdot l_i^2 + d \cdot l_i + e$)

a, b, c, d and e are constants based on the curve fits

- **Similar MERs were developed to estimate the mass of the impact system across this same dataset.**
 - The impact system sizing is estimated based on a solid foam energy absorber which is used in conjunction with impacting an infinitely hard surface^[3].
 - Depending on the impact speed, soil conditions, and kinetic energy at the time of impact, other crush concepts, not considered in the M-SAPE model, could be more mass efficient.
 - e.g. for some ground conditions (e.g. UTTR w/ wet clay), for a highly rigid vehicle, it is highly probable that an impact system will not be required to meet some landing load requirements since deceleration can be achieved solely by ground penetration.^[4]

[3] Kellas S., Mitcheltree R. A. (2002), *Energy Absorber Design, Fabrication and Testing for a Passive Earth Entry Vehicle*, AIAA-2002-1224.

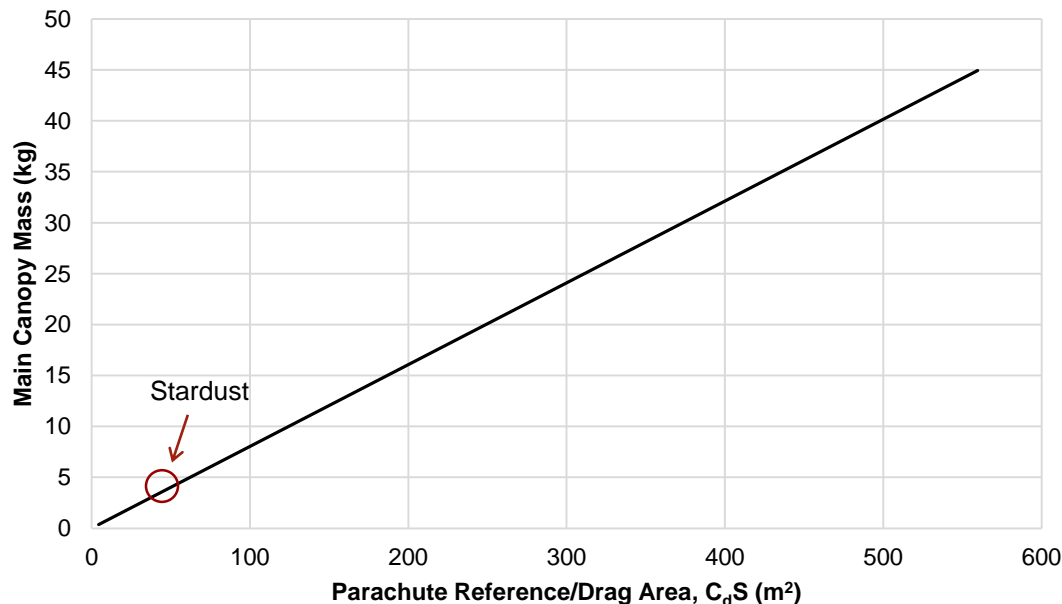
[4] Fasanella, E. L., et. al. (2001), *Low Velocity Earth-Penetration Test and Analysis*, AIAA-2001-1388.



Simplified Parachute Model for Active Vehicle



- A simplified parachute sizing model was developed to assess low velocity landing cases (≤ 20 m/s) based on data for nylon recovery parachutes^[5].
- A parachute C_d of 0.85 was assumed as being representative of likely parachute geometries for MMEEV applications^[6].



[5] Knacke T. W., (1992), *Parachute Recovery Systems Design Manual*, pg. 6-95, Table 6-2.

[6] Knacke T. W., (1992), *Parachute Recovery Systems Design Manual*, pg. 5-3, Table 5-1.



Simplified Parachute Model for Active Vehicle (cont.)



- **The parachute system is sized to provide the desired landing / terminal velocity.**
 - Resizing of structure for opening loads and additional mass for the necessary power, commanding, and data handling system needed for parachute deployment are not considered in this analysis.
 - The mass of a drogue parachute, necessary for transonic stability (due to a likely shift of the vehicle c.g. aft after integrating a parachute system) and used to deploy the main parachute, and its deployment system (mortar) are included.

$$m_{\text{drogue}} = 0.25 m_{\text{main canopy}} , m_{\text{mortar}} = 2.2 m_{\text{drogue}}^{0.5}$$
$$m_{\text{paracute system}} = (m_{\text{main canopy}} + m_{\text{drogue}} + m_{\text{mortar}})$$

- **The total entry mass for the active vehicle is determined by removing the impact system mass and replacing it with the new parachute system mass.**

$$(m_{\text{entry}})_{\text{active}} = [(m_{\text{entry}})_{\text{passive}} - m_{\text{impact system}}] + m_{\text{paracute system}}$$

- Not all of the impact system mass is removed; a payload support structure mass (estimated to be the lesser of the impact system mass or 2 kg) is accounted for.
- **These relationships can then be used to compare the payload mass efficiency ($m_{\text{pay}}/m_{\text{entry}}$) for both the passive and active vehicle models.**

➤ The choice between an active or passive vehicle will depend heavily on the payload landing requirement.

- Which in turn will be driven by science considerations (e.g. sample preservation).

➤ As the payload landing requirement increases (≥ 1000 g), a passive EEV appears to be more beneficial.

- Provides greater payload mass efficiency.

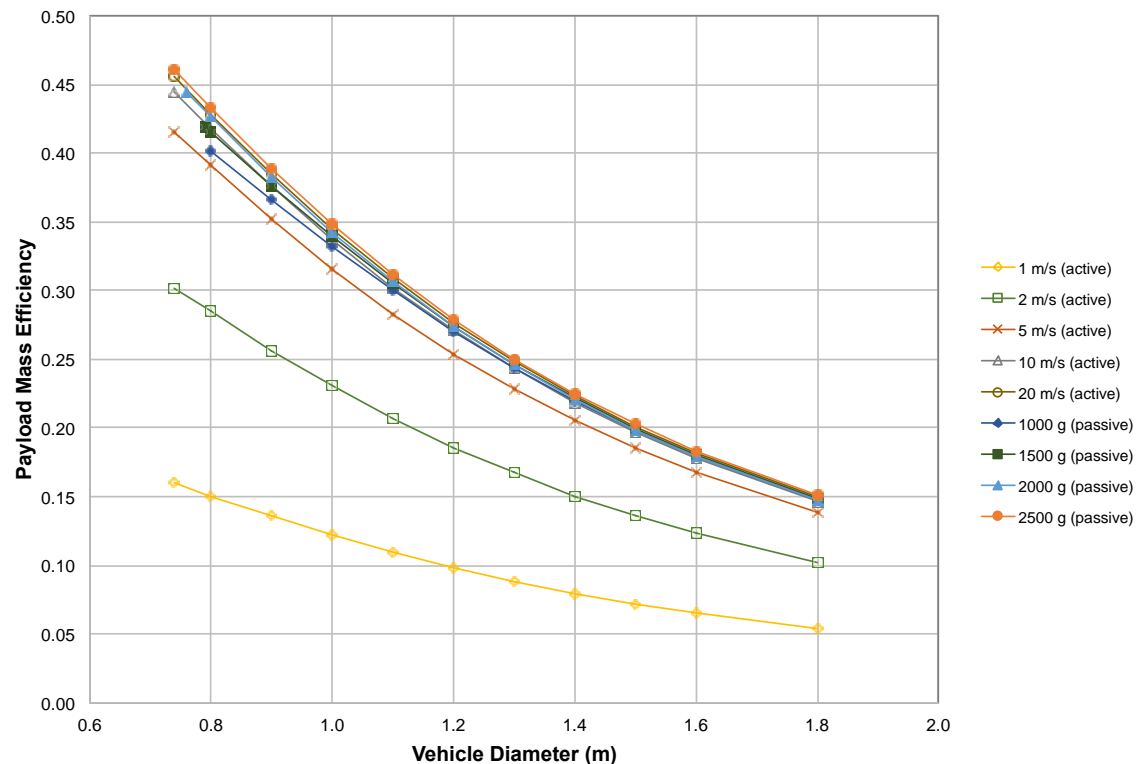
➤ When the payload landing requirement decreases (≤ 5 m/s), an active system is more beneficial.

- As the landing velocity increases, the parachute system mass decreases and becomes comparable to that of an impact system.

➤ For landing velocities ≥ 10 m/s and landing loads ≤ 1000 g's, there appears to be little difference between the passive and active vehicle payload mass efficiency.

- In these cases, other factors, including landing footprint, vehicle configuration, overall system reliability, system complexity, development costs, etc., must also be taken into account.

Payload Mass Efficiency: Passive vs. Active Vehicle Model for 15 kg Payload





BACKUP



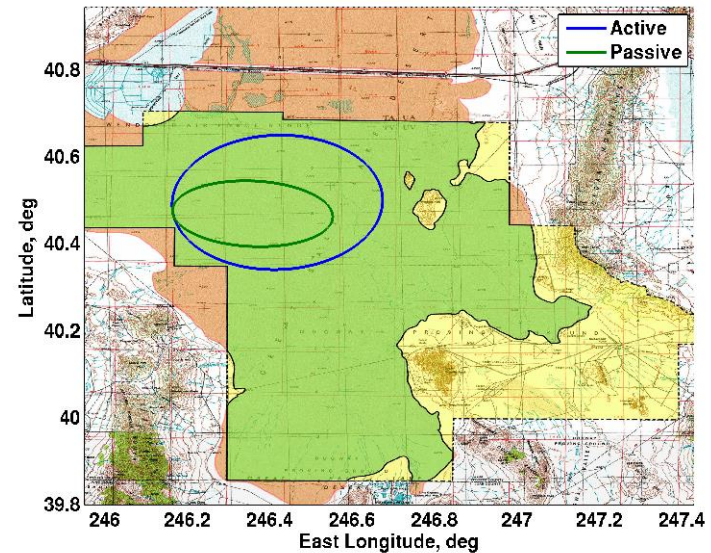
M-SAPE Analysis Assumptions



Input Parameter	Value
Forebody Shape	60° (half-angle) sphere cone
Input Shoulder Radius / Vehicle Radius	0.05
Nose Radius / Input Vehicle Radius	0.78222
Entry Velocity	12.0 km/s
Entry Flight Path Angle	-8.0°
Aftbody TPS Concept	Acusil
Mass Margin	30%
Mass Convergence Criterion	0.001 kg
Max Number of Iterations	20
Forebody TPS / Carrier Structure Concept	PICA-AL-5056
Convective Heat Rate Model	Sutton-Graves
Convective Heat Rate Margin	1.3
Radiative Heat Rate Model	Tauber-Sutton
Radiative Heat Rate Margin	1.0
Impact Foam Stroke Efficiency	80%
Impact Foam Stroke Margin	20%

Other Considerations

- The use a parachute system can have large effects the landing footprint due to increase sensitivity to the atmosphere / winds.
- Adding a parachute system can also complicate the vehicle configuration when considering access to the payload for inserting the samples.
 - Parachute systems are typically packaged towards the aft of the vehicle which will likely shift the vehicle c.g. aft, which could result in decreased aerodynamic stability in the supersonic, transonic, and subsonic regimes.
- The inclusion of additional systems required to support a parachute system and its deployment may also decrease the overall system reliability^[8].



99%-tile Landing Footprint for Passive and Active Concepts assuming Earth GRAM 2010[7] atmosphere and winds (1.2 m diameter vehicle, 20 kg payload, and ~65 kg entry mass).

Parameter	Reliability
Cover Ejected	0.9996
Drogue Deployed	0.9998
Main Chute Deployed (with drogue)	0.9998
Main Chute Deployed (w/o drogue)	0.99
SRC and Canister Found	0.99999
Overall Reliability	0.9992

[7] F.W. Leslie, C.G. Justus (2011), *The NASA Marshall Space Flight Center Earth Global Reference Atmospheric Model – 2010 Version*, NASA/TM-2011-216467.

[8] Eagle Engineering, Inc. (1988), *Risk Analysis of Earth Return Options for the Mars Rover/Sample Return Mission*, NASA-CR-172081.



Case Study



- As a case study, consider a scenario where an MMEEV vehicle diameter is restricted to 0.8 m and the desired payload mass is 13 kg*:

	Passive	Active	Stardust
Landing Conditions	1500 g's	4.6 m/s	4.6 m/s
Payload Mass Efficiency	0.39	0.35	0.28
Entry Mass	33.5 kg	37.1 kg	45.8 kg
Impact or Parachute System Mass	2.5 kg	4.1 kg	4.2 kg
Entry Ballistic Coefficient	β	1.11 β	1.37 β

* Based on Stardust Sample Return Capsule with total mechanism mass of 17.2 kg.

- This shows that the “cost” of a low velocity landing may be an increase in entry ballistic coefficient, which can lead to a significant increase in the aero-thermal environments.
- The difference in entry mass between the active case and the Stardust reference is driven primarily by the difference in the structural configurations of the two capsules, as well as additional considerations to accommodate a parachute system that were not accounted for in this study.
- When comparing to the passive architecture, *IF* there was a desire to maintain the same ballistic coefficient:
- and vehicle diameter and entry mass, then the payload mass would need to be reduced by ~2.4 kg (18%), resulting in a decrease of the payload mass efficiency to 0.32.
 - payload mass, the vehicle diameter must grow to at least ~0.87 m, increasing the entry mass to ~39.7 kg, resulting in a decrease of the payload mass efficiency to 0.32.